NASA Vertical Lift Strategic Direction

Presented at Academia Day

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Outline

- ARMD Six Thrust Strategy
- Integrated ARMD vertical lift strategy
- Revolutionary Vertical Lift Technology (RVLT) project
- RVLT Technical Challenges and future plans
- RVLT technical areas and resources
- NASA External Opportunities and Restrictions
- Summary

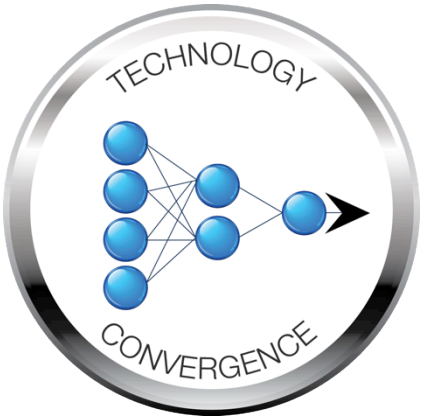
Three Aviation Mega Drivers

NASA Aeronautics research strategy proactively addressing critical long-term needs

Traditional measures of global demand for mobility - economic development and urbanization - are growing rapidly and creating transportation and competitive opportunities and challenges

Large and growing energy and environmental issues create enormous affordability and sustainability challenges

Revolutions in the integration of automation, information, communication, energy, materials and other technologies enable opportunity for transformative aviation systems



NASA Aeronautics Six Strategic Thrusts

Safe, Efficient Growth in Global Operations

- Enable full NextGen and develop technologies to substantially reduce aircraft safety risks

Innovation in Commercial Supersonic Aircraft

- Achieve a low-boom standard

Ultra-Efficient Commercial Vehicles

- Pioneer technologies for big leaps in efficiency and environmental performance

Transition to Low-Carbon Propulsion

- Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology

Real-Time System-Wide Safety Assurance

- Develop an integrated prototype of a real-time safety monitoring and assurance system

Assured Autonomy for Aviation Transformation

- Develop high impact aviation autonomy applications

ARMD Strategic Implementation Plan – A Living Document

Community Vision

Community Outcomes

Research Themes

Table 6. Outcomes and Research Themes for Strategic Thrust 3 – Vertical Lift

Strategic Thrust 3: Ultra-Efficient Commercial Vehicles – Vertical Lift			
	2015	2025	2035
Outcomes		Technology and Potentially New Configuration Concepts that Achieve N+2 and N+3 Levels of Efficiency and Environmental Performance	Technology and Configuration Concepts, Including Low-carbon Propulsion and Autonomy, that Stretch Beyond N+3 Levels of Efficiency and Environmental Performance
Research Themes	**Clean and Efficient Rotorcraft Propulsion** Demonstration and maturation of propulsion and drive system technologies to enable increased vehicle speeds while maximizing propulsive efficiency and minimizing weight penalties **Safe and Certifiable Vertical Takeoff and Landing (VTOL) Technologies** Technologies to extend the flight envelope and maximize performance and efficiency of VTOL aircraft **Advanced Component Noise Reduction** Improvements in lift generation, airframe, and other subsystem components to achieve noise reduction		

System-Level Metrics

Table 5. Targeted Improvements in Vertical Lift Vehicle System-level Metrics

Vertical Lift Targeted Performance (Preliminary)		
Technology Benefits	Technology Generations	
	N+2 TRL 4-6: 2020 First Application 2025-2030	N+3 TRL 4-6: 2025 First Application 2030-2035
Noise (Relative to ICAO 8.4.2/ FAA Stage 3 noise limit)	-10 dB Effective Perceived Noise Level (EPNL)	-14 dB Effective Perceived Noise Level (EPNL)
Fuel/Energy Consumption (Relative to 2005 best in class)	-50%	-60%

Roadmaps for each of the six Thrusts in the SIP are being developed

- **Update the SIP Outcomes, Research Themes and Metrics**
- **Draft under review**

Link to SIP: http://www.aeronautics.nasa.gov/pdf/armd-strategic-implementation-plan.pdf

Civil Rotorcraft: Past Major Studies

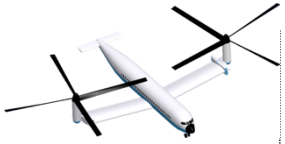
1987-1991: Civil Tiltrotor Missions and Applications: Phase I & II (Boeing, Bell, Boeing Vertol, NASA)

1995: Report to Congress: Civil Tiltrotor Development, Vol. I & II

1993-2001: NASA Short-Haul Civil Tiltrotor Concepts

2000-2003: Runway Independent Aircraft Studies (Bell, Boeing, Sikorsky; NASA funded)

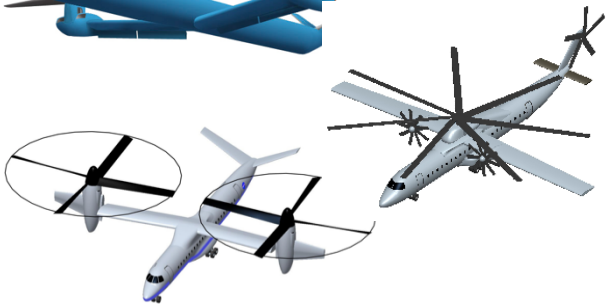
2004-2005: NASA Heavy-Lift Rotorcraft Systems Investigation



2009-2011: Modeling High-Speed Civil Tiltrotor Transports in the Next Generation Airspace (SAIC et al; NASA funded)

2009: Advanced Vehicle Concepts and Implications for NextGen (Sensis et al; NASA funded)

2009: Aircraft System Analysis of Technology Benefits to Civil Transport Rotorcraft (Boeing; NASA funded)



Base R&T	Short-Haul Civil Tiltrotor / Aviation Systems Capacity		Vehicle Systems	Fundamental Aero
• 8-75 pax • 270-300 kts	• 40 pax • 315 kts	• 80, 90, 120 pax • 310-350 kts	• 120 pax • 350 kts	• 30-120 pax • 250-350 kts

Vertical Lift Outlook and Community

- Unique capabilities of vertical lift and hover provides potential for exceptional access and mobility in both commercial and public good applications
  - Specialized missions performed by current configurations
  - Entirely new future missions for advanced conventional and non-conventional configurations
  - Projected market growth[1] of vertical lift (helicopters and civil drones) is > $6B in next 5 years
- Community: Established and Emerging Manufactures and Users
- Community has a wide spectrum of configurations and a broad range of interest
  - Large and small-scale vehicles
  - Conventional and unconventional configurations
  - Range of propulsion options from small electric motors to large turbomachinery
  - Crewed and un-crewed configurations
  - Established and emerging manufacturers and users
- All configurations need improvement in cost, speed, payload, safety and noise

[1]http://www.businessinsider.com/uav-or-commercial-drone-market-forecast-2015-2
[1]The World Rotorcraft Market, Vertiflite, Vol. 61, No. 3, 2015

Envisioned Common Civil Configurations and Missions in 2030 & beyond

	Configurations				
	Very Light	**Light**	**Medium**	**Heavy**	**UltraHeavy**
Missions	•inspection •photography •filming •spraying •mapping •weather •surveillance •delivery	•police •training •traffic/ news •power line service •spraying •cargo	•police •EMS •traffic/news •tourism •executive •charter •oil platforms •SAR •cargo	•oil platforms •disaster relief •cargo •logging •construction •firefighting •commuter (30 pax)	•commercial transport (90-120 pax) •disaster relief •civil reserve aircraft fleet •cargo
	autonomous capability				
Overarching Strategy	Enable a broad expansion of vertical lift applications • Improve current configuration cost, speed, payload, safety, and noise • Open new markets with new configurations and capability • Capitalize on convergence of technology in electric propulsion, autonomy and flight controls				

blue highlight: new mission and/or new configuration

Ultra-Efficient Commercial Vehicles, Vertical Lift (draft)

Vertical Lift Community is broad; plan should be inclusive

- **Large and small-scale vehicles**
- **Crewed and un-crewed configurations**
- **Established and emerging manufacturers and users**

NEW DRAFT Community Outcomes (proposed):

Increased capability of vertical lift configurations that promote economic benefits and improve accessibility for new and current markets

New vertical lift configurations and technologies introduced that enable new markets, increase mobility, improve accessibility, and reduce environmental impact

Vertical lift vehicles of all sizes used for widespread transportation and services, improved mobility and accessibility, with economic benefits and low environmental impact

NEW DRAFT New Research Themes:

- **Clean and Efficient Propulsion**
- **Efficient and Quiet Vehicles**
- **Safety, Comfort, Accessibility**
- **ModSim and Test Capability**

Note: System Level Metrics still under consideration

NASA Vertical Lift Research Themes

- **Clean and Efficient Propulsion**
  - Research and development advancing the efficiency of turbomachinery and power transmission.
  - Expanded integration and development of alternative propulsion systems for vertical lift configurations.
- **Efficient and Quiet Vehicles**
  - Research and development of technologies and configurations that optimize performance and speed and minimize noise and cost.
- **Safety, Comfort, Accessibility**
  - Research and development of technologies and capabilities that improve passenger and public safety during operations.
  - Research and development of technologies that improve ride quality.
  - Research and development of technologies, configurations and operational concepts that improve access to transportation and services.
- **ModSim & Test Capability**
  - Research and development of modeling tools and experimental methods that support advancements in configuration design, development and operation.

NASA Vertical Lift Strategy

- **Deliver key capabilities and technologies that directly benefit our partners in industry and government**
  - Validated tool for modeling noise from entire vehicle
  - Validated tools for multi-discipline vehicle design, analysis and optimization
  - Tools for mission analysis and configuration trade studies
  - Technologies for pilot workload reduction
  - Design for improved turbomachinery efficiency
  - Approach for high power-transmission efficiency established
  - Lower drag for increased speed, range, payload and lower fuel burn
- **Focus on key technologies that enable US industry to expand the global vertical lift market while setting new standards in noise, performance and reliability**
  - Process to characterize and predict human response to noise
  - Validated tool to calculate acoustic footprint in real-time
  - Efficient alternative propulsion options
  - On-board systems to enhance safe operations in icing conditions, degraded visual environments and confined or urban areas
  - Validated, high-fidelity computational algorithms for full configuration simulations
  - Tools for mission analysis and CONOPS of unconventional configurations
- **Focus on capabilities and technologies that eliminate barriers for clean, efficient, quiet, autonomous vehicles operating in urban and isolated environments**
  - Best practices for integration of lift and propulsion systems
  - Methods for real-time low-noise operations
  - Active and prognostic condition-based maintenance systems to reduce life-cycle costs
  - Methodology to analytically certify composite primary structure for loads and impact response
  - Advanced experimental methods for ground and flight test validation of configurations

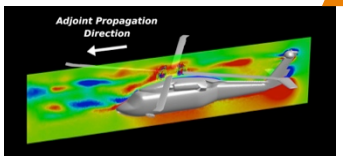
Enhancing Vertical Lift Capabilities

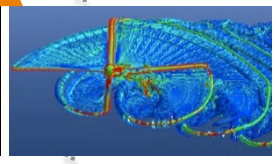
FUTURE CAPABILITIES

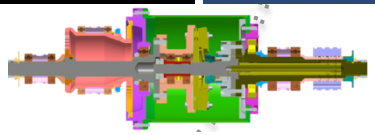
Transformative Concepts

(e.g. hybrid electric, autonomy, new concepts)

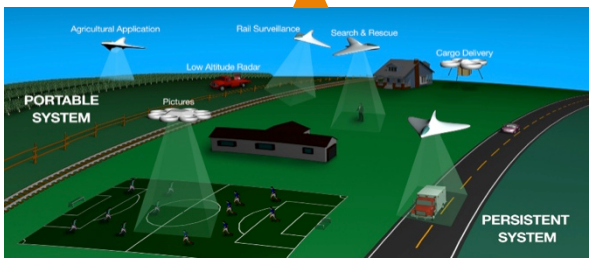
Research focus in Subsonic Rotary Wing and Rotary Wing Projects (2006–2014)







Revolutionary Vertical Lift Technology Project (2015+)
Innovative technologies, tools & concepts (e.g. low noise, efficient propulsion, & optimization technologies)



Unmanned Traffic Management System

- Key to safely opening new markets
- Important de-confliction with existing vertical flight

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Revolutionary Vertical Lift Technology Project

Develop and Validate Tools, Technologies and Concepts to Overcome Key Barriers for Vertical Lift Vehicles

Vision

- *Enable next generation of vertical lift vehicles with aggressive goals for efficiency, noise, and emissions to expand current capabilities and develop new commercial markets*

Scope

- *Technologies that address noise, speed, mobility, payload, efficiency, environment, safety*
- *Conventional and non-conventional very light, light, medium, heavy and ultra-heavy vertical lift configurations*

RVLT Research Themes & Tech Challenges

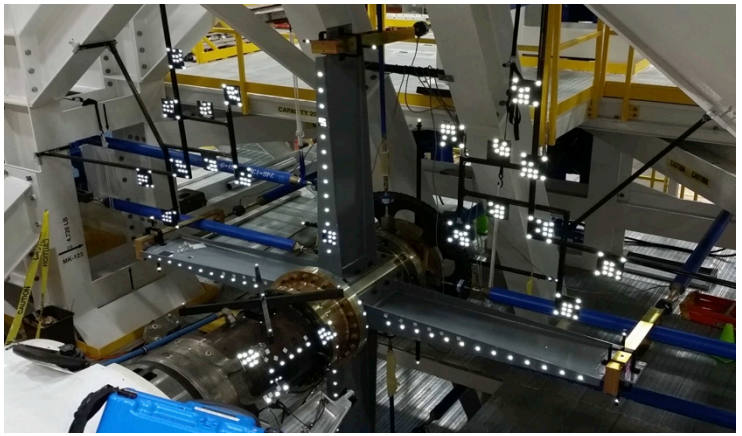
Research Theme	Technical Challenges 2015-2020	Other Research in Theme Area 2015-2020	Addresses
Clean and Efficient Propulsion	**Variable Speed Power Turbine Technology Demo:** Demonstrate 50% improvement in efficient operational capability **Two-Speed Drive System Demo:** Demonstrate two-speed drive system with 50% rpm reduction	• High efficiency gas generators • Hybrid electric propulsion • Condition Based Maintenance methods	Speed, mobility, efficiency, environment, payload, noise, safety
Efficient and Quiet Vehicles **Safety, Comfort, Accessibility**	**Technical Challenge: Demonstration of an MDAO Design Process for Vertical Lift Vehicles (draft)** **Technical Challenge: Demonstration of Design and Flight Operation Methods for Reduced Vertical Take-off and Landing (VTOL) Aircraft Noise Impact (draft)**	• Internal cabin noise • Crashworthiness • Icing for rotorcraft • Hover performance and prediction • High fidelity CFD modeling and accuracy	Noise, speed, mobility, efficiency, safety, environment, payload

RVLT Project Areas of Investment, FY15-16

Multi-Speed Propulsion

Variable-Speed Turboshaft Engines
- Variable-speed power turbine
- High-efficiency gas generators

Multi-Speed Lightweight Drive Systems
- Advanced gearbox components and configurations
- Variable-speed transmission
- Condition based maintenance

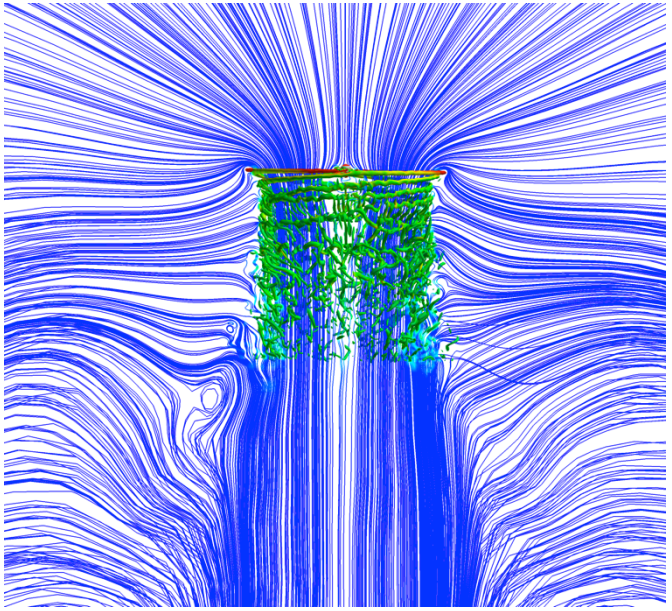


Tiltrotor Test Rig metric hardware, with photogrammetry retro-reflectors

Multi-Disciplinary Design, Analysis, and Optimization

Validated Multi-Disciplinary Design Tools
- High-fidelity modeling
- Conceptual design and sizing tools
- Experimental validation and methods

Optimization Environment for Conceptual Design
- OpenMDAO framework



High-resolution hover calculation in NFAC 80x120 Wind Tunnel

Safe and Certifiable VTOL Configurations

Low Noise Optimized Rotor
- Acoustics
- Aeromechanics and Rotor Performance

Safety and Environment
- Impact Dynamics
- Community Noise and Response
- Icing

NASA Vertical Lift Project Research Areas

Ames Research Center

- Aeromechanics
- Computational Methods
- Flt Dyn & Ctrl
- Experimental Capability
- System Analysis
- Autonomy

Glenn Research Center

- Drive Systems
- Engines
- Hybrid Electric Systems
- Icing
- System Analysis
- Condition Based Maintenance

Langley Research Center

- Acoustics
- Aeromechanics
- Experimental Capability
- Computational Methods
- Crashworthiness
- Autonomy

- *Typical NASA research is TRL 1-5, sometimes 6*
- *Typical NASA products are feasibility studies, technology demonstrations, research reports*
- *Partnerships enable faster technology transition to DoD and industry*

Resources and Facilities

FY15-16 RVLT Summary

~65 Civil Service Workforce
~ $20M per year (includes salary)

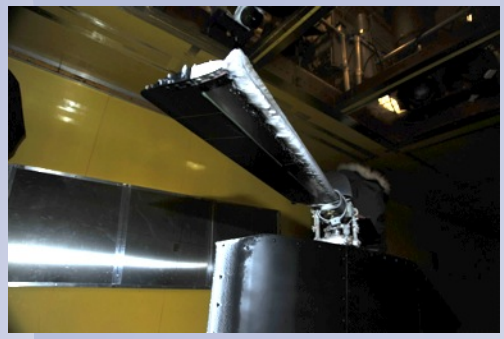
Anticipate similar level of funding for FY17-20

Ames Research Center

- National Full-Scale Aerodynamics Complex (NFAC)
- Supercomputing Complex (NAS)
- Vertical Motion Simulator

Glenn Research Center

- Compressor Test Facility (CE-18)
- Transonic Turbine Blade Cascade Facility (CW-22)
- Transmission Test Facilities (ERB)
- Icing Research Tunnel



Langley Research Center

- 14- by 22-Foot Subsonic Tunnel
- Transonic Dynamics Tunnel
- Landing and Impact Research
- Exterior Effects Synthesis & Sim Lab
- Mobile Acoustic Facility

Partnerships and Collaborations

Key Partnerships

- Vertical Lift Research Centers of Excellence (VLRCOE) SAA through FY21
- Army and Vertical Lift Consortium (Icing research, Airloads workshop)
- Naval Research Laboratory
- Smart Twisting Active Rotor (STAR) International partnerships
- Pratt and Whitney
- General Electric
- Joby Aviation
- United Technologies Research Center
- Bell Helicopter
- PSU-ARL
- A&P Technologies

Key Agreements

- NASA-Army MOU for Collaborative Research in Aeronautics, August 2007
  - Army Aeroflightdynamics Directorate (ADD/AFDD)
  - Army Research Laboratory, Vehicle Technology Directorate (ARL-VTD)
  - Army Applied Aviation Technology Directorate ADD/(AATD)
- German DLR Framework: rotor experimental optical methods
- NLR LOA—aircraft flyover noise

Upcoming External Opportunities

Leading Edge Aeronautics Research for NASA (LEARN) Fund for Non-NASA Researchers

- http://nari.arc.nasa.gov

NASA ARMD Research Opportunities in Aeronautics (ROA 2015)

- http://www.aeronautics.nasa.gov/nra.htm

With Respect to NASA Collaboration

NASA is funding the VLRCOE under the same guidelines as NASA Research Announcements (NRAs) ARMD Research Opportunities in Aeronautics (ROA) are funded

This means that NASA needs to follow the guidelines established for the ROA NRA

http://www.hq.nasa.gov/office/procurement/nraguidebook/

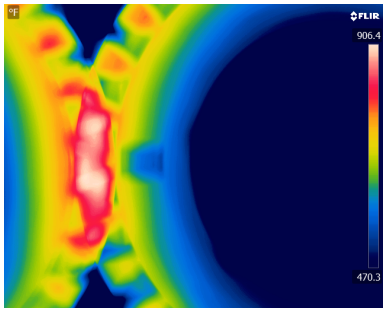
http://nspires.nasaprs.com/external/solicitations/summary.do?method=init&solId={11703C5E-6355-BCAF-FFB8-E117299C8B42}&path=open

The major point is:

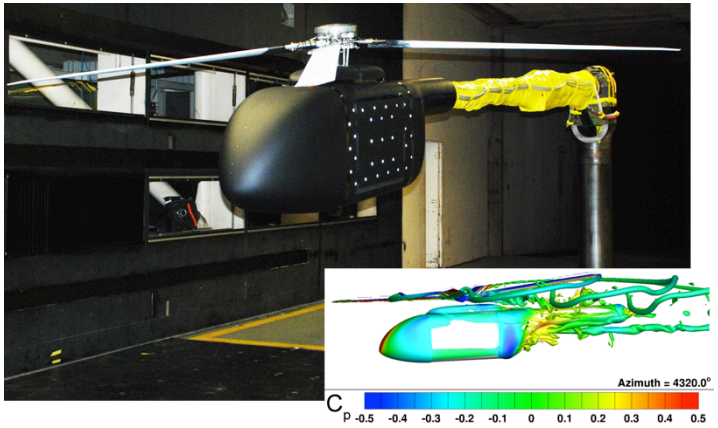
NASA personnel or their work should not be included on the proposals for any tasks. NASA personnel can and will collaborate as appropriate with selected tasks after award. However, NASA personnel and their work should not be considered or listed as part of the proposal team.

Summary

- NASA RVLT is focused on overcoming significant barriers to the use of vertical lift vehicles in expanded missions
- Providing technology leadership
  - Technologies to optimize rotor designs and flight operations for low noise considering other operational constraints
  - Efficient configuration concepts that reduce fuel burn
- Technologies that improve noise, speed, mobility, payload, efficiency, environment, safety
- Enable vision of the future for vertical lift
  - Technologies to advance innovative concepts

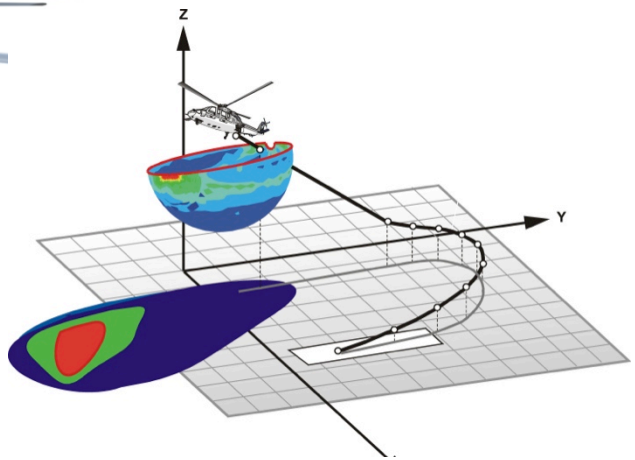


Thermal imaging of gear teeth

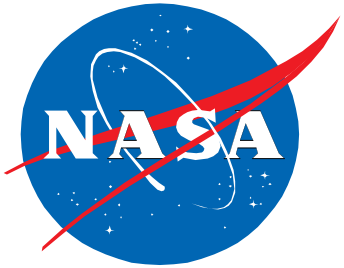


Fuselage drag reduction

Conceptual design



Noise Modeling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NASA 2016 ARMD Organization